

Design and Modeling of Thermo-syphon System Solar Energy Electric Generation for Domestic Household Appliance

Dr. Nigussie Mulugeta, Abebe Zeleke Amedie

Abstract— This research introduces new, renewable power production technology using solar energy as driving energy source using four main mechanical components; those are flat plate collector, cooling tank, hydro turbine unit and piping system including nozzle and diffuser. The combination of those four unit form closed system which can produce micro electric power. The proposed work in this research is renewable and non-pollutant thermo-syphon system solar energy electric power generation which is new technology.

Expected outcome of the research is to produce micro electric power for the rural community at the level of household electric power demand, which is used to lightning and charging of small electrical equipment's with viable reduction of biomass and fossil fuel used for lightning.

This research mainly focus on the rising of water in collector pipe by means of density difference and delivered into cooling tank, which can cool hot water coming from the collector and then give potential energy to drive turbine, set on the bottom position 1.35 meter away from the cooling tank. Working fluid circulate in the system using thermo syphon principle. Sun power serves as the driving force to generate thermal energy on the flat plat collector and it raise temperature of water at 51oc. This variation of temperature in the system develop 2.4cm height variation between the solar collector and cooling tank side, variation of height make flow of water from top of collector riser pipes to cooling tank (reservoir) by means of gravity

Index Terms—TSS, Electricity, Domestic, renewable.

I. INTRODUCTION

Renewable energy production is the recent competitive technology, in the world, sectors of energy production seek alternative energy source since now, for the world environmental protection as well as the production used to residential commercial and industrial purpose. Which gives for most broadly, rural area having limitation of on grid power therefore most Wide range electric power produces from solar energy, widely concentrated collectors are used to change the working fluid in to steam. Which is use to drive, steam turbine in the power plant unit, such like system is need high investment cost as well need wide area to harvest steam with mega tone production capacity for electric power or industrial application.

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Among the technologies of solar power water heating system is common and the easiest technology in the solar thermal application technology such as in residential, commercials as well in the industrial application. Most researchers used to establish good design of solar water heater using passive circulation system, which have great advantage to save electrical power cost, by means of reducing electric power consumption of the pump as well as the system serves as alternative option of pumping, such mechanism like natural circulation system in the absence of electric power supply and pumping apparatus's.

Different researchers save the electric power consumption used to pump water at high elevation using thermo-syphon system and other mechanical advantage. This is the basic interesting foundation of the area to being study on this research paper. This research would find out solution for minor domestic household appliance which need electric power especially for rural community of our country. By Produce electric power for one domestic Household. appliance consumption level, considering daily power consumption needs of the following specified applications for mobile charging, television, radio and lighting purpose, from solar energy passive water circulation system the proposed research face the challenge to harvest electrical power for domestic house applications, such as for mobile charging, television, radio and light operating purposes which would be the most best economical environmental friendly system as well without any operating cost.

Using thermo-syphon system principle in the flat plat collector, integrate with natural cooling system in the cooling tank and micro hydro turbine, to change potential energy of water into mechanical energy, to produce electrical energy from the entire system.

STATEMENT OF THE PROBLEM

Regardless of the growing interest of our world, living standard rapidly changes, and electric power consumption, domestic house hold appliance increases day to day activities to improve living standard. It happen in our country, Ethiopia is rapidly changing since now, demand of the electric power in the country is not sufficient even for small house holding appliances, like lighting & charging of small power consumption electrical equipment's, specially the rural communities of our country have not get electric power for house holding appliances uses yet, topographical landscape locational set of most rural communities out of hydro power grid line, this may take high investment cost, to distribute the national hydro electric grid power for individual communities of rural area, because of the topographical difficulty and distribution equipment limitation.

Even if the rural community of our country being a back bone of the country by driving the agricultural sector. However, those sectors not get electrical power for their daily domestic appliance, the living standard of the rural community still on the traditional way of life, till now, society used biomass and fossil fuel for domestic application which being footprint on the ecology as well as their health issue, due to pollution of indoor air in the resident and rapid increment of environment pollution. Therefore the consumption of biomass and fossil would reduce, by supplying electric power to the end user. Since the problem is exist, due to the former listed reasons. This research propose to develop new technology which can address to solve those problems.

A. Objective

Design and modeling of thermo-syphon system solar energy electric power generation for domestic household appliance.

B. Specific Objective

Determination mechanical energy needed to produce electric power for house holding application.

Determine required temperature of water in the collector

Design and modeling of solar collector for the specific purpose (to lift water at top position in the system).

Determination of maximum flow rate in the collector.

Design and modeling of cooling tank (using natural cooling system).

Design and modeling of min-hydraulic turbine for the specific function.

C. Working Principle of Proposed System

Due to variation of density the static head develop on the side of collector and on the side of cooling tank and free delivery pipe vary the elevation or height of collector side make variation of height to reach at equilibrium static pressure head of working fluid opposes the static pressure which came from the cooling tank side. This principle put on the proposed system, show figure 1:1 below variation of water density in the tube can be generate, by add up thermal energy from solar energy on the solar collector this give the variation of density of water inside in the collectors, which can proved density variation of water it also give height variation in the collector and cooling tank side, before reaching the max height of less denser fluid in the collector side, it should bend in the cooling tank direction. The discharge at the top return in the cooling tank.

The height of the solar collector outlet and cooling tank position have variation of height due to Volume expansion of the working fluid, the fluid which reach in the top pipe of the collector, flow in the cooling tank and hot fluid which came from the collector cool by natural cooling mechanism in the cooling tank to recover the density of working fluid in the desired value and the flow again assist by gravity and strike on turbine blade.

Water is selected to be working fluid in the system, the main reason of selecting water is it have high density to produce high energy in the turbine unit relative to other fluid and it also free from chemical reaction formation with steel pipes, different fitting equipment's and mostly available with minimum cost almost zero.

Conversion sun radiation energy into heat energy is the most common and well developed solar conversion technology

which is used to different applications. Solar energy may change in different form of energy like mechanical energy and electrical energy using different technology and also use as thermal energy source, the key main parameter is the efficiency of the converter device. In this system thermal energy gain from the sun which used to change density of water in the system.

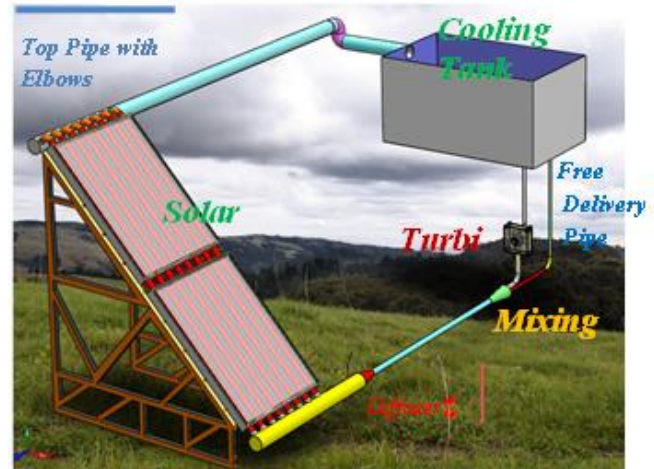


Figure 1:1 Thermo-Syphon Solar Energy Electric Generation system

Pressure is the compressive force per unit area, and it gives the impression of being a vector. However, pressure at any point in a fluid is the same in all directions but variation of pressure with depth vertical direction in a gravity field. Pressure in a fluid increases with depth because more fluid rests on deeper layers, and the effect of this “extra weight” on a deeper layer is balanced by an increase in pressure in the opposite side. Pressure in a fluid at rest does not change in the horizontal direction. this static pressure Principe assure the balance of pressure occur in the two side of the system show in figure 1:1 the solar collector side and the cooling tank side, incline and vertical side of the system which can make static pressure balance when it fill with fluid.

Equilibrium static pressure equation p_c and p_t are density of water in solar collector and in the turbine side respectively. Where h_c is vertical total height of collector and h_t is total height of free delivery pipe and the height of cooling tank. Vertical height of collector is different from the total vertical height of free delivery pipe and height of cooling tank due to variation of water density low density water found in the collector to reach equilibrium.

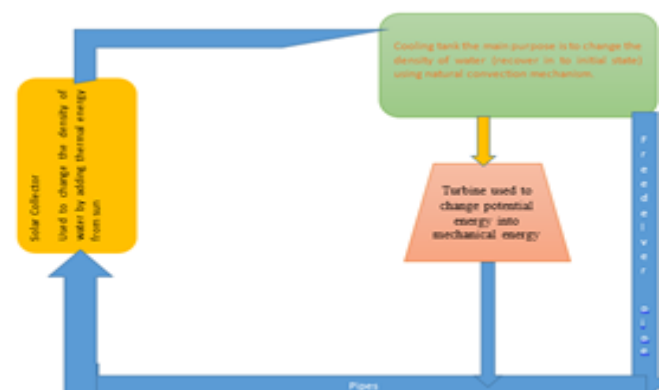


Figure 1.2. Process diagram of the system

Free delivery pipe used to make the static pressure head in the side of turbine which can resist gravitational pressure or static pressure develop in the solar collector side. The objective of using free delivery pipe is to protect the back flow during less thermal energy applied on collector plat. The static equilibrium pressure reach from both side of the collector and turbine side.

static head in the system h_c should be greater than h_t , from the difference of h_c and h_t value before reaching the maximum variation of head it must change the direction of flow in to the inlet of cooling tank, to fill cooling tank, which is set parallel to the collector top surface with small variation of height the system governed by basic static pressure equilibrium equation

$$\rho_c g h_c = \rho_t g h_t \quad (1-1)$$

$$h_c = \frac{\rho_t h_t}{\rho_c} \quad (1-2)$$

$$h_c > h_t \quad h_c - h_t = \Delta h \quad (1-3)$$

The variation of height in equation three show the expansion of working fluid in the solar collector with temperature variation. The net mass transfer due to expansion of water flow in cooling tank through top pipe which have very low slop from solar collector to cooling tank.

METHODOLOGY

To address the proposed research two main phases are execute mainly up to the end of the research. First theoretical analysis of data and other important parameter for the proposed system model the Second software simulation for required phase, the first action perform by taken theoretical analysis of different parameters after collecting of solar radiation data of the selected site which is Bahir Dar available amount of solar incident radiation on the surface of the site from different sources.

Then determine static head need, solar water heater collector design is execute which is used to determine flow rate amount in the system from available solar radiation required to heat water in the collector pipes then design and selection of appropriate water cooling system for the cooling tank unit finally design and selection of micro hydraulic turbine for the proposed thermo syphon system solar energy electric power generation system, after the entire theoretical design analysis is complete, specification of material list out.

At the second phase, using solidwork software to simulate different parts system in the model and to prove the manufacturability and to show real working condition, simulation of model.

II. LITERATURE REVIEW

Thermo-syphon system (natural circulation system) is used into different application, as an advantage of pumping of low density fluid to transport at the desired position. Heating of water for domestic purpose is simple and effective way of utilizing solar energy the incident of solar radiation energy convert into heat energy and finally transfer this heat to working fluid for different applications, natural free circulation, solar water heating system are most applicable in small installation for domestic hot water circulation which reduce energy cost, paid for electric consumption and complexity of the system according to all natural circulation system are self-regulated the greater the energy received, the more vogues circulation, by overcoming the resistance of the system components, due to the difference in density of the hot

water in the flow pipe and density of the hot water in return pipes and cooling tank. Heat transfer surface of the solar collector should operate (work) with the objective of achieving high efficiency with low friction losses. Different literature state about thermo-syphon system, can minimize the electric power consumption to pump the different fluids. [8] Concentrated solar energy used for electric powered generation, heat from the sun an endless source of clean free energy. Commercially feasible and quickly expanding, this type of solar technology requires strong, direct solar, radiation and is primarily used as a large, centralized source of power for utilities. In contrast, photovoltaic cells are, effective in wider range of regions and applications. Concentrated solar power plants generate power best during the late afternoon during peak demand and can substitute fossil fuel plants that emit greenhouse gases which can be cause of climate change. As energy storage technology continues to advance, more concentrated solar power plants will be able to provide base load power throughout the night but it need large harvesting area and high investment cost so this cannot use for small scale power generation.

Numerous studies have been performed on natural circulation solar water heating system In1979 in United States; National Bureau of standards programmer monitored five types of pumped solar energy water heating systems along with natural circulation water heating systems.

It was not that the best performance was obtained from the natural circulation for direct pumping purpose unit [11]. In another study in United States [3], reported by, the indirect natural circulation water heating system achieved higher. Solar fractions in comparison to the equal sized pumped systems. [1] Higher flow rate leads to higher collector efficiency factor. However, it also leads to higher mixing in tank and therefore, a reduction in the overall solar water heating system efficiency. Performed side-by-side experimental investigations to evaluate the influence of the flow rate on the thermal performance of two direct solar domestic hot water systems [14]. Bucolic O.Bolaji stat the collector natural circulation solar water heater lift water in the storage tanker high static head collector by the temperature gradient of the ambient and the collector of 51o which make a flow rate of 0.1 kg /s. Difference in overall performance for conventional and reduced flow rates.[4] also investigated thermal performance of indirect solar domestic hot water system employing an external counter-flow heat exchanger to transfer heat from the solar collector to the portable water. The results of their investigation showed that the system exhibited optimum flow rates at either side when the collector is without optimal efficiency performed, theoretical investigation to determine, the optimum collector flow rate in solar domestic hot water systems having an external counter flow heat exchanger [5]. Their analysis was based upon the assumption that the overall exchanger. From different literature and investigation show that due to temperature different there is a tendency to make flow in the system, not only in the domestic purpose as well as for industrial and nuclear power plants used this system to cool reactors.

Investigation shows as collectors are serve as to lift water in cooling tank position, which have small elevation different from the outlet of collector pipes, by assisting the static and dynamic pressures of fluid which is flow in the return pipe, the flow can be continuous in the closed system by change in

temperature of the working fluid, the change of temperature leads to change density and viscosity characteristics of fluids. After the fluid enter in the cooling tank it change the potential energy due to gravity it strike small hydro turbine blades to form mechanical rotational power which is used for electric power production.

Solar Water Heater

Heating water is usually burning by firewood in the country areas and by fossil fuel energy kerosene oil, petroleum gas coal and electricity in metropolitan areas, all type of energy source can be replace by solar energy, solar water heating (SWH) systems can replace or reduce electric energy consumption used.[13]Solar water heater SWH is accepted and readily available technology, which use renewable energy different types of SWH are available and can be used for different application. Domestic hot water usually uses small system applications while larger systems are used in industrial applications.

There are two types of water heating systems based on the type of the circulation natural circulation and forced circulation. Natural circulation solar water heater simple in design and low cost, forced circulation water heaters are used in freezing climates and for commercial and industrial process heat. [12]

But at the specific problem natural circulation system design is choice used in simple solar water heater to cause flow motion through a collector. The density difference is created within the solar collector when heat is added to the liquid.

Suitable design of solar water heating system will give maximum benefit to rise water in the top part of system. Solar hot water system need suitable sizing of different components and must considering on solar insulations and hot water demand. Solar radiation is adequate to heat water up to 65 -80co in the collector.

III. FLOW ANALYSIS IN THE PROPOSED SYSTEM

3.1. Introduction

Circulating water in the system is assisted due to the present of gravity and thermal energy from the sun, till it reaches at the top desired position of the collector riser pipes the entire system is depend on natural circulation system, internal flow depending on whether the flow is forced or natural circulation system. In this system we consider internal flow where the pipes are fully developed flow in each delivery and riser pipes is completely filled by water and flow is drive primarily by means of pressure difference which is develop by gravitational force and thermal properties of water. On the proposed system thermal energy collect from the solar energy in to the collector used to change the working fluid properties such as density and dynamic viscosity of working fluid. Change in temperature of water in the collector can make volumetric expansion of water, those two properties are significant parameter in natural circulation flow analysis.

The fluid in such applications is usually forced to flow by means of pump through flow section. Particular attention need to friction which is directly related with pressured drop and head loss during flow through pipes of the system in the side of the collector. [3] Free delivery pipe turbine deliver and also the turbine outlet. Analysis of pressure drop is used to determine the pumping power requirement or amount of force required in the system to make the flow in the range of required parameter.

Thermal energy required in the flow have direct relation with viscosity and density of water which can be major parameter in the pressure drop analysis. So Analysis of pressure drop in the system have directed relation with the collector required thermal energy.[7] Typical in the system involves pipes of different diameters connected to each other by various fittings or elbows to control the flow rate, and transport water in the cooling tank. Different size of pipes are used interchangeably throughout the system, circular cross section pipes are fit in the system show in the figure1:2 and it also minimize surface contact area with flowing fluid inside the surface of the pipe relative to other cross section contours area.

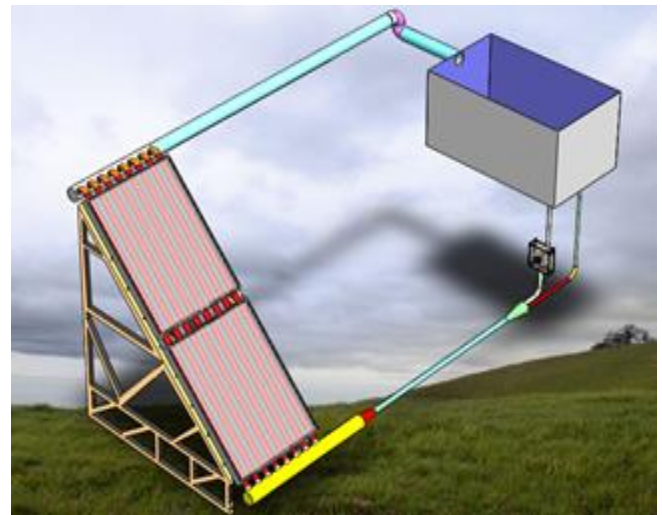


Figure 3:1 Isometric view of the proposed model

3.1.1. Conservation of Mass in the System

Conservation of mass principle can apply on the system, the net mass transfer to or from a control volume with the environment is zero. During operation time of the system energy can transfer into or from system in the form of thermal energy. Energy transfer occur on the two part of the systems, those are in the collector and in the cooling tank. Thermal energy leave from the system boundary total mass within the system show in figure 3:1 total mass entering in the collector and total mass leaving in the cooling tank is equal so net change in mass of the system is zero during at any change of time because the entire system is clos system or control mass but thermal energy in the form of heat can pass the boundary layer of solar collector and the cooling tank. Which is the valuable energy to change the density of water and its viscosity properties, when water reach or enter in the portion of the collector from the cooling tank.

$$m_{in} - m_{out} = \Delta m_{cv} = 0 \quad (3.1) [8]$$

Then the time rate of change mass within the control volume can be expressed as the rate of change of mass with in the control volume for the special case of no mass crossing the control surface so the proposed system is control mass or closed system. No flow across the boundary but water circulate inside the system by means of expansion due to the thermal energy gain from the solar collector and heat rejection in the cooling tank.

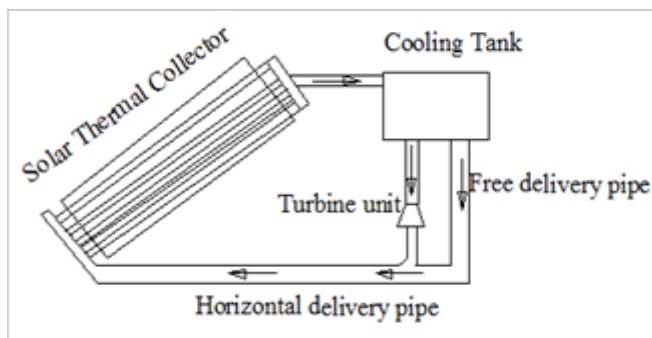


Figure 3:2 control mass system diagram of the mode.

3.1.2. Daily power consumption

The power consumption of the equipment use in the rural community of the country is different for their appliance need so that this power production system is based on the following appliances of power consumption level for one rural house holed level estimated.

Table 3.1 Appliance and their load required

No	Appliance	Item quantity	Power consumption	Operating hour	Total consumption
1	Lightning lamps	3	35 watt	4	420 Whr
2	Television	1	75 watt	4	300 Whr
3	Radio	1	25 watt	4	100 Whr
				Total power	820 Whr

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Table 3.1 Appliance and their load required

Daily electric power consumption, capacity of the hydropower plant is primarily a function of two main variables which have direct relation with the required load. Those are water flow rate and hydraulic head for the proposed system the two main variables are determine start from the required load amount Thermo-Syphon Solar Energy Electric Generation system use the principle of hydro power on the electric generation unit. The required power capacity from hydropower system is determine using the following basic formula.

Mostly efficiency of hydraulic turbines are from 85-98%[10] the whole parametric properties of the above formula are dependent on some conditions such as temperature and pressure is the most critical parameter for density of water the efficiency of turbine also affect by the density variation and flow rate also affect by the head of the system So that those parameters are dependent of the site temperature and atmospheric pressure the average temperature of the site is 27oc here in Bahire Dare[17] at this temperature and atmospheric pressure density of water is around 997 kg/m³ [9] which indict the cooling tank outlet water temperature must be 27oc so the cooling system should achieve the indicting temperature at the outlet side.

Mechanical energy in the system

To achieve the power demand indicating in Table 1:1 is the potential energy of the system available amount of mechanical energy should convert into kinetic energy on the turbine side velocity of free falling object. [9]

$$v = \sqrt{2gh} \dots\dots\dots (3-2)$$

To get the desired amount of power the head which can be used in the system should full fill this demand and the flow rate have relation with velocity and cross section area of pipes in the system it found using simple attrition, the required head is 1.35 meter in the turbine side.

$$V = 5.15 \text{ m/s}$$

Available mechanical Power at the end of the pipe is determine

$$\text{Force} = \rho gh \times A \dots\dots\dots (3-3)$$

$$\text{Power} = \rho gh \times A \times V \dots\dots\dots (3-4)$$

Where A is the cross section area of pipes from standard pipe catalogue [9] internal diameter of turbine delivery pipe is selected 30.1mm galvanized steel pipe, which is suitable for the system, take density of water at temperature of 27oc. Cross section area of turbine delivery pipe.

$$A_{cp2} = 7.1 \times 10^{-4} \text{ m}^2$$

$$\text{power} = \rho ghA\sqrt{2gh}$$

$$\text{power} = 48.28 \text{ watt}$$

$$\text{Daily production capacity} = 11587.2 \text{ whr}$$

This is available mechanical energy in the system without taking any additional mechanism which can increase by means of nozzle to maximize power in the system possible parameter is velocity which can be change by means of nozzle in the inlet of turbine unite. To increase jet which intern into the turbine unit.

The required system should generate power for four production hour in the sit of Bahir Dar, the average sunshine hour on Bahir Dara is 5 hour show on the Figure 6:9 World isolation map yearly average of day light hour of sunlight. So that total daily available energy is 11.5872kwhr, but all of the energy cannot convert in to electrical power some of might loss due to irreversibility.

Flow analysis Conclusion

In the lower part of the model flow is pressurized by gravitational force the required amount of dynamic pressure in the outlet of the diffuser, make the uphill flow in the riser of the absorber plate which is the required parameter. Flow velocity in the entry of mixing nozzle is low in the flow simulation analysis graph show in the flow trajectory data the velocity is in the range of 0.8-1.2m/s at outlet of nozzle the velocity increase up to 3.451m/s, through the horizontal pipe the velocity is constant with small pressure drop.

On the lower part of 140 mm diameter pipe the static pressure is require to develop, up to which can resist, static and frictional head loss in the collector riser pipes, after the diffuser dynamic pressure result on the range of 22,528.79-24,781.69 Pa in the flow simulation analysis. The require amount of pressure which make uphill flow in the collector riser pipes are 24,740.85 pa, this value is less than maximum value show in the simulation dynamic pressure data with the difference 40.84 pa, but in collector riser pipe friction head loss is greater than 40.84 pa, pressure it can interrupt the continuous flow in the collector pipes. To protect interruption of flow, viscosity of water must change easily due to thermal energy gain from the sun. Required density variation to make the head at equilibrium position of 2.4cm increment, the collector riser pipe water density should be reduce the value is

determine by taking total system head in the side of turbine and collector head with additional required head which is 2.4cm, Water have density in side of turbine 997 kg/m3.

$$\rho_c = \frac{\rho_t g h_t}{g h_c}$$
$$\rho_c = 985 \text{ kg/m}^3$$

This is the required amount of density in the collector, water density reduce by 12 kg/m3 amount. To change density of water below the value of 985 kg/m3 water should heat above 51oC temperature with atmospheric pressure. [9] This can be perform using flat plat collector solar water heater devices to assure the system head increment 51oC is the mean value of temperature which can get in the flat plat collector and the atmospheric temperature of the site.

IV. SOLAR WATER HEATER COLLECTOR DESIGN

Selection of solar collector

Different types of collectors are used for different application the most common type is concentrating collector and flat plat collector types the selection criteria is based on the energy required for the specific application. In the thermo syphon system thermal energy used to change the density of water in the collector to create additional head (height) water column in the riser pipe so that the amount of height column need is 4.57cm in the system to get this amount of height is execute from the density change of water so that flat plate collector can change the temperature of water up to 75oc at atmospheric pressure.

This temperature variation of water give density version and positive volumetric expansion coefficient of water, due to density variation the static pressure equation in the two vertical column give height variation with common gravitational force.

$$\rho_c h_c = \rho_t h_t \dots\dots\dots \text{Equation (4-1)}$$

On the proposed system is to produce electrical power from the height of 2 meter so if we heat water up to 75oC in the solar collector hc can be greater height relative to ht so that the result have given variation of 4.57cm.

If we use evacuated tube solar collector temperature of water reach upto150oC with atmospheric temperature density can reduce according to saturated water tabular data [9] with this temperature we can make column head difference of up to 17.54cm which is adequate amount of column head to make bend on pipes, but water reach at the indicating temperature, it change to gas state, it difficult to condense easily and to change the temperature into atmospheric temperature level.

Flat Plate Collector

The flat plat collector, simplest type of solar energy collection system is used to absorb solar energy convert into heat and then transfer this heat to fluids. It absorbs both the beam and diffuse radiation mostly the collector system build from different parts which is combined to give the desired system, flat plat collector have tendency to change saturation properties of water volumetric expansion of water due to temperature gradient can make flow in the lower pressurized side in the system.

Common Parts of Flat Plate Collector

Tube which is used to conducted heat transfer from the absorb to the working fluid

Absorber plate flat corrugated or groove plate with tube. Insulation minimizes heat loss from the back and side of the collector.

Transparent glass cover to protect the reflection radiation and to minimize the upward heat loss.

V. HEAT TRANSFER AND LOSS IN FLAT PLAT COLLECTOR

The easiest way of using solar radiation is solar water heater system, for low temperature heating purposes. Most of the low temperature solar heating systems depend on the use of glazing, because it has the ability to transmit visible light and block infrared radiation. High temperature solar collectors use mirrors and lenses. Solar thermal engines are an extension of active solar heating and help to produce high temperatures, in passive solar water heating system also use to reduce the energy consumption of pumping and the power required to heat the water for the desired purpose in the system. Black surfaces absorb solar radiation more than any other color and, therefore, when a surface is blackened it will absorb most of the incident solar radiation. Continuous flow of solar radiation onto such a surface will increase its temperature. [8]

For low temperature collectors heat loss reduction methodology is used, transparent glass cover to protect the reflection radiation and minimize the upward heat loss and insulation minimizes heat loss from the back and side of flat plat collector

5.1. Thermal Performance of Different Solar Collectors

Performance of solar thermal systems for heating and power generation based on their performance solar collectors, therefore experimental measurement of thermal performance of solar collectors are important and necessary. Experimental performance data is need for design purposes and to select appropriate type of collector to the desired purpose. The thermal performance of solar collector is determined based on establishing efficiency curve from the measured instantaneous efficiencies for a combination of values of incident radiation, ambient temperature and inlet fluid temperature. Instantaneous efficiency of collector under steady state conditions can be established by measuring the mass flow rate of the heat transfer fluid, its temperature rise across the collector, temperatures output range of different type of collectors are show in below.

Table 5:1. Thermal performance of solar collectors [6]

Motion	Collector type	Absorber type	Conc entration ratio	Indicative temperature range (o c)
Station ary	Flat plat collector (FPC)	Flat	1	30- 80
	Evacuated tube collector (ETC)	Flat	1	50 -200
	Compound parabolic collector (CPC)	Tabular	1-5	60 -240
Single Axis tracking	Liner Fresnel reflector (LFR)	Tabular	5-15	60-300
	cylindrical trough collector (CTC)	Tabular	10-40	60-300
	parabolic trough collector (PTC)	Tabular	15-50 10-58	60-250 60-400
Two axis tracking	parabolic dish reflector (PDR)	Point	600-2 000	100-1500
	Heliostat field collector (HFC)	Point	300-1 500	150-2000

Table 5:2. Thermal conductivity of material at room temperature. [9]

Material	Thermal conductivity k (w/m k)	K in solidwork software library
Silver	429	
Copper	401	390
Gold	317	
Iron	80.2	Ductile iron 75
Glass	1.4	
Glass fiber	0.043	A Glass fiber 0.025
Air	0.026	
galvanized steel	23	23
Cast Stainless steel	37	37
Steel AISI 1020	47	47

Analysis of Heat Transfer Coefficients in the Model

Heat loss to the surroundings from the plate through the glass cover which on the top of the collector and insulter is laminated the side and the bottom part of collector, system loss take place by conduction convection and radiation equivalent losses of the system is the commulative of those all losses.

Collector Energy Balance

$$\dot{m}C_p(T_{fo} - T_{fi}) = A_c F_r [\alpha T - u(T_{fi} - T_{fo})] \quad (5-1)$$

Where, $Q = \dot{m}C_p(T_{fo} - T_{fi})$

Where CP of water at 51oc is 4.184 kJ/kg [9] water temperature in the outlet side required to be 75oc, the temperature in the inlet side is taken as the atmospheric temperature when the effective ness of the cooling system is taken to be maximum 27oc. So that require amount of thermal energy or heat is determine with the system mass flow rate of 4.676 kg/s.

$$Q_r = \dot{m}C_p(T_{fo} - T_{fi}) \quad (5-2)$$

Where Q_r is the required max amount of heat energy on the collector to rise temperature of outlet water up to 75oc.

$$Q_r = 938,417.088 \text{ watt}$$

This is the maximum required energy to perform temperature gradient from atmospheric temperature to maximum temperature rise of water in the flat collector, taking the inlet temperature equal with site atmospheric temperature (Bahir Dar) but maximum required temperature to change the density of water in the collector is 51oc to collect this much amount of solar power the collector geometry should be determine to collect thermal energy amount from the available solar radiation on the set.

$$Q_a = \dot{m}C_p(T_{fo} - T_{fi})$$

Where Q_a is the required amount of average heat energy on the collector

$$Q_a = 469,208.544 \text{ watt}$$

to $\alpha < 1$. A pressure.f.18kg/m/+3 ine side can be he countinous flow ery pips side is around 202 202 202 202 202 202 202 202 202 202 202 202 202 202 202

The total area of the collector and its efficiency is should achieve desired amount of thermal energy to make flow in the collector pipe. The volume flow rate inside the collector in the upward direction is 4.7474l/s which is determine in the flow analysis part of the model, The average value of water density ρ in the inlet and outlet of the pipe is determine using maximum output temperature of water and average atmospheric temperature of the set which is 75 and 27oc respectively at those temperature value of average density is.

$$T_{av} = 51^{\circ}\text{C}$$

At this temperature density of water is 985 kg/m3 from the respective value saturation properties of water table. [9]

Convective Coefficients

Convective heat transfer coefficient happened in the collector in different stage pelt to cover can be analysis using thermal resistance, thermal conductivity of absorber material of collector.

$$h_{1c} = \frac{1}{R_3}$$

$$h_{1c} = N_u \frac{k}{L} \quad (5-3)$$

N_u the nusselt number the ratio of the convective heat transfer to the conductive heat transfer L is the gap between pelt and glass cover and K is thermal conductivity of absorber plate On the low surface of heated plate isothermally the product value of Grf and prf value from the experimental tabular data is 105 -1011 taking the average value of the tabular data 106 [5]

$$N_u = 0.1(G_{rr}P_{rr})^{1/3}$$

$$N_u = 10$$

$$h_{1c} = 19.35 \text{ w/m}^2\text{k}$$

Thermal conductivity of absorber plat 80.2 w/m2k data from table 4:2 and the characteristic length of the collector is proposed to be inclined and have the effective length of 2.83m. From the glazing cover to ambient.

$$h_{2c} = \frac{1}{R_1} \quad (5-4)$$

$$h_{2c} = 2.8 + 3 \times V_a$$

Average Velocity of wind in the specific location around Bahir Dar, Where V_a is the wind velocity of the atmosphere is 2.5 m/s over the collector.[17] Taking the average minimum velocity of air on Bahir Dar.

$$h_{2c} = 10.3 \text{ w/m}^2 \text{ K}$$

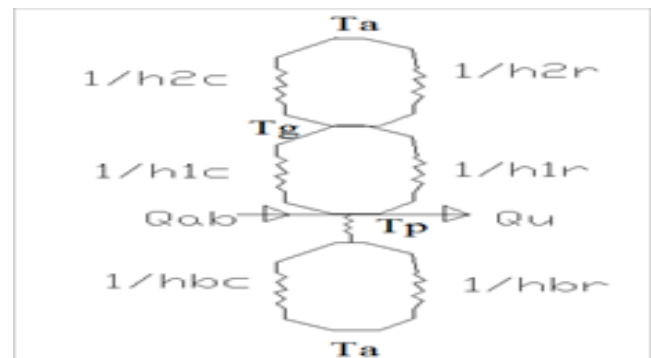


Figure 5.1 Thermal circuit diagram of the flat plate solar collector [6]

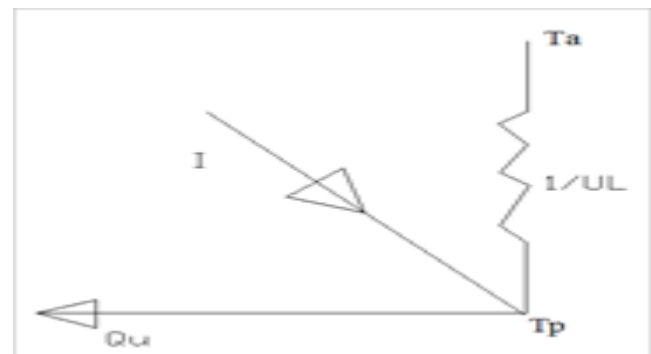


Figure 5.2 Equivalent thermal circuit diagram

Radiation heat transfer coefficient from plate to cover h_{lr} is the coefficient of radiation heat loss, collector plate to the

cover expressed taking the maximum temperature of absorber plate 80oc and temperature glass taken 27oc equal with the average atmosphere temperature of Bahir Dar.[17]

$$h_{1r} = \frac{1}{R_4}$$

$$q_{rad} = h_{1r} (T_p - T_g) \quad (5-5)$$

$$h_{1r} = \epsilon_{eff} \sigma \left\{ \frac{(T_p + 273)^4 - (T_g + 273)^4}{T_p - T_g} \right\} (4-7)$$

Table 5:3 Emissivity value of different material

Polished copper	0.03 [9] Or 0.01 [6]
Polished silver	0.02
Polished Stainless	0.17
Galvanized steel	0.28
Glass	0.92
Cast iron	0.21
Galvanized iron sheet	0.28

The effective emissivity value between absorber plate and glazing system is determine from emissivity value of absorber plate and glass cover, absorber material in the system is cast iron and glass cover used to protect the top loss, emissivity value of those materials are show in the table 4:3.

$$\epsilon_{eff} = \left[\frac{1}{\epsilon_p} + \frac{1}{\epsilon_g} \right]^{-1} \quad n \quad (5-6)$$

$$\epsilon_{eff} = 0.272$$

$$h_{1r} = \epsilon_{eff} \sigma \left\{ \frac{(T_p + 273)^4 - (T_g + 273)^4}{T_p - T_g} \right\}$$

$$h_{1r} = 2.16 \text{ w/m}^2 \text{ K}$$

Radiation heat loss from collector plate to the cover.

$$q_{rad} = h_{1r} (T_p - T_g) \quad (5-7)$$

$$q_{rad \text{ loss}} = 114.48 \text{ w/m}^2$$

The value of Stefan- Boltzmann constant σ is.

$$\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$$

From glazing cover to ambient.

$$h_{2r} = \frac{1}{R_2} \quad (5-8)$$

The sky temperature gradient is determine by the following temperature.

$$T_{sky} = 21^\circ \text{C}$$

The radiative heat transfer coefficient is expressed as.

$$h_{2r} = \epsilon_g \sigma \left\{ \frac{(T_g + 273)^4 - (T_{sky} + 273)^4}{T_g - T_a} \right\}$$

$$h_{2r} = 5.467 \text{ w/m}^2$$

Top Loss Coefficient

The total heat transfer coefficient from collector plate to cover is expressed as the sum of h_{1c} and h_{1r}

$$h_1 = h_{1c} + h_{1r} = \frac{1}{R_3} + \frac{1}{R_4} \quad (5-9)$$

$$h_1 = 21.69 \text{ w/m}^2 \text{ K}$$

The total over all heat transfer coefficient from the cover to the ambient is expressed as

$$h_2 = h_{2c} + h_{2r} = \frac{1}{R_1} + \frac{1}{R_2} \quad (5-10)$$

$$h_2 = 15.767 \text{ w/m}^2 \text{ K}$$

The effective top heat transfer coefficient from absorber plate to ambient is determine as follow.

$$u_t = \left[\frac{1}{h_1} + \frac{1}{h_2} \right]^{-1} = \left[\left(\frac{1}{R_3} + \frac{1}{R_4} \right)^{-1} + \left(\frac{1}{R_1} + \frac{1}{R_2} \right)^{-1} \right]^{-1} \quad (5-11)$$

$$u_t = 9.13 \text{ w/m}^2 \text{ K}$$

The rate of heat loss from the top per unit area can be determine

$$q_{top \text{ loss}} = u_t (T_p - T_a) \quad (5-12)$$

Maximum loss in the top surface of the collector, when the temperature of absorber pelt is reduce after heat is transfer to water flow in the riser pipes, required amount of water temperature is 51oc at the collector pipe end.

The value of u_t is need iteration in general the cover temperature T_g is not known an arbitrary value of T_g is assumed and then at the mean value of temperature h_{1c} , h_{1r} , h_{2r} are calculated and then using these value of top loss coefficient T_g can determine as follows.

$$h_1 (T_p - T_g) = u_t (T_p - T_a) \quad (5-13)$$

The value of glazing temperature is obtained from the energy balance

$$T_g = T_p - \frac{u_t}{h_1} (T_p - T_a)$$

$$T_g = 46.1^\circ \text{C}$$

Which give the maximum temperature of the glass, taking the maximum temperature range in the glass.

$$q_{top \text{ loss}} = 174.383 \text{ w/m}^2$$

Back Loss Coefficient

Heat loss from the plate to ambient by conduction through the insulation and subsequently by convection and radiation from the bottom surface casing the bottom loss coefficient is given, insulation material at the back of the collector side is fiber glass which have the thermal conductivity if 0.043 w/m2 k from table 4:2, [7] the effective length of the collector is 2.83m.

$$u_b = \frac{k_{in}}{l_{in}} \quad (5-14)$$

$$u_b = 0.0152 \text{ w/m k}$$

Edge Loss Coefficient

Energy loss from the side of the collector casing is same value as that from the back, in the collector side similar material is used in the model and thickness of fiber glass is the same as that of the back insulation, the edge loss is determine.

$$u_e = u_b \frac{A_e}{A_c} \quad (5-15)$$

Having two separate collector plates in the system, the total surface area of the collector

$$A_c = 2.025 \text{ m}^2$$

Total area of the collector, $A_{ct} = 4.05 \text{ m}^2$

Edges of the collector area,

$$A_{1e} = 0.12 \text{ m}^2$$

Which have two similar front sides,

$$A_{1et} = 0.24 \text{ m}^2$$

Edges of the smaller side of collector area, $A_{2e} = 0.108 \text{ m}^2$

Which have two similar sides,

$$A_{2et} = 0.216 \text{ m}^2$$

Total edge area of collector

$$A_{eT} = 0.912 \text{ m}^2$$

$$u_e = 0.0034 \text{ w/m k}$$

Over All Heat Loss Coefficient

The overall heat loss coefficient U_L is the sum of the top, bottom and edge loss coefficient.

$$U_L = U_t + U_b + U_e$$

$$U_L = 9.148 \text{ w/m}^2 \text{ K}$$

The overall heat lost by the absorber to the ambient per unit area per unit time can be determine, using the maximum range of temperature which is absorber plate temperature and ambient temperature and overall heat loss coefficient.

$$Q_L = U_L (T_p - T_a)$$

$$Q_L = 174.7268 \text{ w/m}^2$$

Thermal Analysis of Flat Plate Collectors

Basic Energy Balance Equation

Useful energy output per unit time of collector area A_c is difference between the absorbed solar radiation and thermal loss, monthly average diffused radiation incident on a horizontal surface ($\text{kWh/m}^2/\text{day}$) of 22 year average value is taken from the atmospheric science data center, for the specific location at latitude and longitude of the 11.37° and 37.67° which is a site of Bahir Dar.

Nasa surface metrology and solar energy data from atmospheric science data center, diffuse radiation direct normal radiation and tilted surface radiation are not calculated when the clearance index (k) is below 0.3 and above 0.8, this parameters used for sizing and pointing of solar panels and for solar thermal application.[17]

$$Q_u = A_c q_u = A_c [q_{ab} - U_L (T_p - T_a)] \quad (5-16)$$

Where Incident solar energy,

$$q_{ab} = (\tau_0 \alpha_0) I(t) \quad (5-17)$$

Where τ_0 and α_0 are the transparency of the glass cover and absorptivity of the absorber τ_0 value of the glass which is used for the system have 0.89 and absorptivity of absorber plate is 0.76 cast iron is used. Daily production hour is 4 hour. So that the average value of radiation incident on a horizontal surface is divided in to 2 hour and multiple by production time so that 870 w/m^2 .

$$q_{ab} = 588.468 \text{ Wh/m}^2$$

$$Q_u = 1160.6652 \text{ wh}$$

The instantaneous efficiency of the collector defined as the ratio of useful gain to incident solar energy over the entire collector area which is expires in different forms.

$$\eta_i = \frac{Q_u}{I(t)A_c} = \frac{q_{ab}}{I(t)} - \frac{U_L (T_p - T_a)}{I(t)} = (\tau_0 \alpha_0) - \frac{U_L (T_p - T_a)}{I(t)}$$

$$\eta_i = 0.3294$$

Collector Efficiency Factor

Collector efficiency factor is defined as the ratio of actual useful heat collection rate to the useful heat collection rate on the collector absorbing plate T_p is local fluid temperature T_f Collector efficiency factor is symbolized by \dot{F} . The collector efficiency factor is constant for any collector and fluid flow rate it increase with an increase in center to center distance of the collector pipe and also it increase with increase of the pipe thickness and the thermal conductivity of material is change but in the system the thermal conductivity of the pipe is the same from inlet of the pipe to the outlet of the pipe.

$$\dot{F} = \frac{Q_u}{A_c [q_{ab} - U_L (T_f - T_a)]} \quad (5-18)$$

$$\dot{F} = 0.7768$$

Over all heat transfer coefficient of the collector determine from collector efficiency factor using the total loss coefficient.

$$\dot{F} = \frac{U_0}{U_L} \dots \dots \dots \text{Equation (5-19)}$$

$$U_0 = \dot{F} U_L$$

$$U_0 = 7.106 \text{ w/m}^2 \text{ K}$$

Temperature Distribution in Collector Pipes

Where \dot{m} total collector mass flow rate and n is the number of riser laying on the absorber plate and C_p is the specific heat of water at temperature of 20°C its value is 4.182 kJ/kg K and the total mass flow rate in the collector pipe is 4.676 kg/s with eight (8) collector riser pipes, inside and outside diameter of pipes 45mm and 51mm respectively from the standard pipe catalogue dimension of copper pipe select based on head loss consideration section 3.6.5 iteration graph 3:6. This analysis is execute using the ambient average temperature of Bahir Dar which is 27°C, useful heat gain per unit flow length transfer to the flow fluid can give different temperature distribution in the riser pipes. Where L is length of the collector pipe effective length of pipe is 2.83m

$$Q_{ul} = L \dot{F} [q_{ab} - U_L (T_p - T_a)] \quad (5-20)$$

$$Q_{ul} = 630.01 \text{ W/m}^2$$

Energy balance of pipe along the flow direction through single tube, temperature distribution of water in the collector is determine using the following formula. [6]

$$\frac{\dot{m}}{n} C_p \frac{dT_f}{dx} - n L \dot{F} [q_{ab} - U_L (T_o - T_a)] = 0 \quad (5-21)$$

dT_f temperature of fluid range from ambient temperature to maximum required $dx = 51 - 45 = 6\text{mm}$

$$dT_f = (T_o - T_a)$$

To is pelt temperature which equal to the outside collector pipe temperature on the contact surface
Average Ambient temperature of the set is 27°C

$$\frac{\dot{m}}{n} C_p \frac{dT_f}{dx} - [2.7\text{m} \times 0.914 [588.468 \text{ Wh/m}^2 - 9.148 (T_f - 27)]] = 0$$

Temperature distribution of water in the riser pipe.

$$dT_f = (T_o - T_a) = 6.05 \times 10^{-6} [588.468 \frac{\text{Wh}}{\text{m}^2} - 9.148 (T_f - 27)]$$

\dot{F} and U_L constant with the boundary condition T_f and T_{fi} is equal at the initial condition, total contact area of absorber and collector riser pipes are in figure 4:5 below, some parts of riser pipe outside surface area have surface contact with absorber plate grooved surface parts.

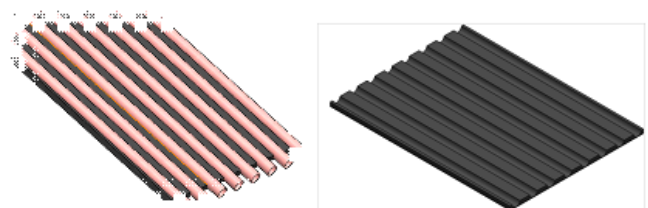


Figure 5.3 surface contact area of absorber plat and collector riser pipes in the grooved part

Where r is the outside pipe radius which is 0.0255m. Cylindrical part surface contact length, can

determine using the radius of pipe and angle envelop in the groove part, half part of collector pipes are set in the groove of absorber plate which is half of the parties enclosed by grooved plate.

$$w = s = d \theta r \dots \dots \dots \text{Equation (5 - 22)}$$

$$w = s = 0.08007 \text{ m}$$

$$\frac{T_f - T_a \left(\frac{q_{ab}}{u_l} \right)}{T_{fi} - T_a \left(\frac{q_{ab}}{u_l} \right)} = e^{\left[\frac{-n U_l w F' L}{\dot{m} C_f} \right]} \quad (5 - 23)$$

$$e^{-0.000739} = 0.9992$$

Tf final outlet temperature of water

$$\frac{T_f - T_a \left(\frac{q_{ab}}{u_l} \right)}{T_{fi} - T_a \left(\frac{q_{ab}}{u_l} \right)} = 0.9992 \quad T_f = 55.768^\circ \text{C}$$

The temperature beyond the desired temperature, collector assure, it can proved more temperature to the fluid starting from the inlet delivery pipe to the top side outlet fluid.

Temperature is vary due to several case, which have the average radiation on the surface 622-720 w/m² the required temperature of fluid should take on the analysis of the viscosity reduction when the temperature increase this parameter is the desired one to minimize the flow resistance force.

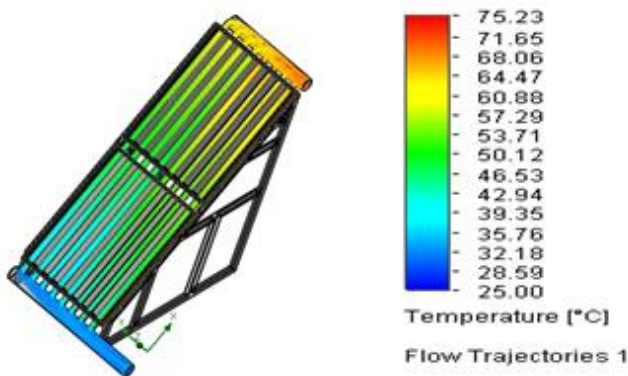


Figure 5.4 Variation of water temperature in the collector pipes

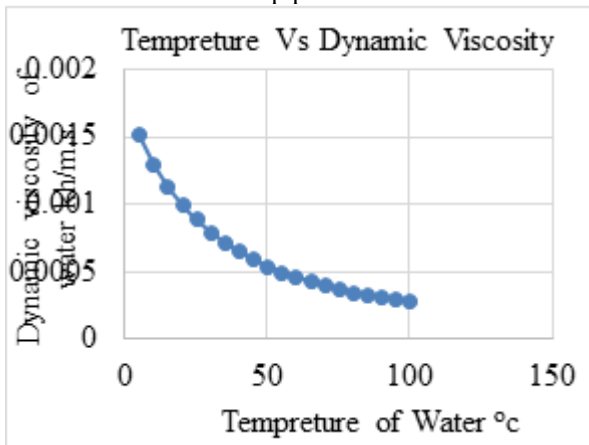


Figure 5.5 Graph of dynamic viscosity Variation of water in the collector pipes

Collector Heat Removal Factor

Collector heat removal factor is the ratio of the actual useful energy gain of fluid to the entire collector useful energy gain from the sun. The quantity FR is equivalent to the effectiveness of a conventional heat exchanger, which is

defined as the ratio of the actual heat transfer to the maximum possible heat transfer. The maximum possible useful energy gain (heat transfer) in a solar collector occurs when the whole collector is at the inlet fluid temperature and determine as follow.

$$F_R = \frac{\dot{m} C_p (T_{f0} - T_{fi})}{A_{Cp} [q_{ab} - u_l (T_{fi} - T_a)]} \quad (5 - 24)$$

$$A_{cp} = n w L,$$

Where Acp is contact area of collector and absorber plate

$$A_{cp} = 1.726 \text{ m}^2$$

$$F_R = \left[\frac{\dot{m} C_f}{A_{Cp} U_L} \right] \left[1 - \exp \left(\frac{A_{Cp} U_L}{\dot{m} C_p} F' \right) \right] = 0.7756$$

Collector Flow Factor

Collector Flow Factor is the ratio of Collector heat removal factor to collector efficiency factor.

$$F'' = \frac{F_R}{F'} = \left[\frac{\dot{m} C_f}{A_{Cp} U_L F'} \right] \left[1 - \exp \left(\frac{A_{Cp} U_L}{\dot{m} C_f} F' \right) \right] \quad (5 - 25)$$

$$F'' = \frac{0.7756}{0.7786} = 0.998$$

The actual useful energy collected (transfer) in the fluid is determine

$$Q_{\text{useful}} = A_{Ct} F_R [q_{ab} - u_l (T_p - T_a)]$$

Total collector surface area Act is 4.05m²

$$Q_{\text{useful}} = 2339.662 \text{ wh}$$

The instantaneous thermal efficiency of a flat plate collector is given by

$$\eta_i = \frac{Q_u}{I_{(t)} A_{Ct}} = F_R \left[(r\alpha) - \frac{U_L (T_{fi} - T_a)}{I(t)} \right]$$

$$\eta_i = \frac{1160.6652 \text{ wh}}{870 \text{ Wh/m}^2 \times 4.05 \text{ m}^2} = 0.3294$$

Due to variation of temperature, density of water, which is found in side in the collector pipe reduce show in figure 4:7 in simulation analysis.

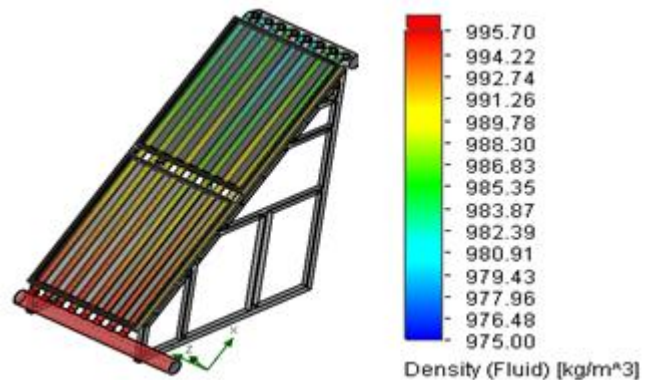
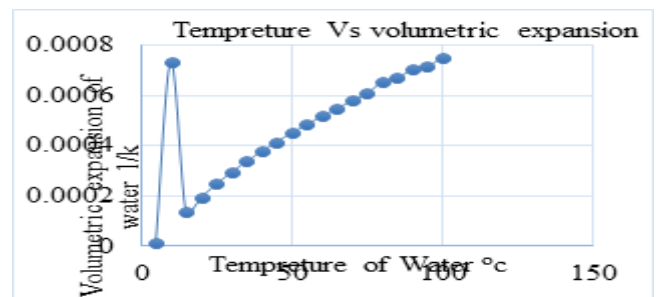


Figure 5.6 Variation of water density in the collector



5.7 Graph of Volumetric expansion of water simulation result in the collector pipes

On the flow simulation result on the model density of water in the collector reduce, from inlet to outlet, this variation provide volumetric expansion and buoyancy force make flow upward direction with small flow rate in each pipes of the collector.

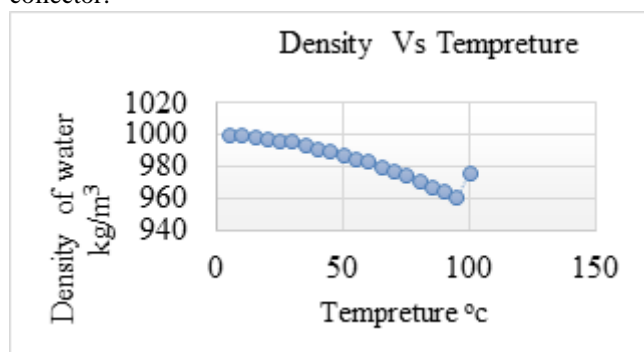


Figure 5.8 Graph of Variation of water density in the collector pipes

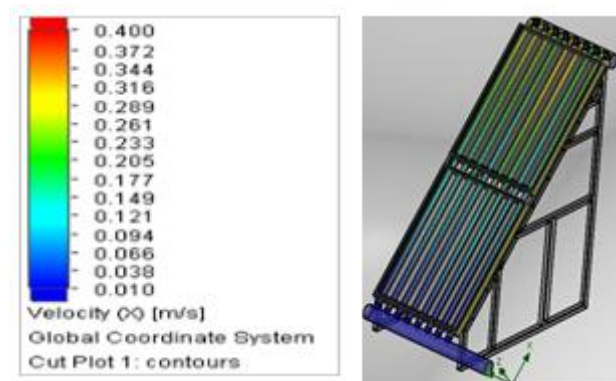


Figure 5.9 Velocity of water in the collector pipes due to buoyancy force

Flow in the collector is very low due to dynamic pressure of water in the uphill direction is reduce because, present of frictional force, gravitational force and also on the horizontal delivery pipe of the system at the end of the last collector riser pipe flow is reduce due to friction flow velocity is increase on the top part of each riser pipes. it show on the simulation. When each collector riser pipe water flow at the top long horizontal pipe which is connect to cooling tank to cool hot water in the cooling tank it be ready to flow in the vertical down warred direction and to hit turbine blade.

VI. COOLING TANK

6.1. Heat Transfer

All modes of heat transfer require the existence of temperature difference, and all modes of heat transfer from the high temperature medium to lower temperature one. Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as result of interactions between the particles. Conduction can take place in solids, liquids, or gases.

In gases and liquids, conduction is due to the collisions of the molecules during their random motion. In solids, it is due to the combination of vibrations of molecules in a lattice and the energy transport by free electrons. [4] It is observed that the rate of heat conduction through layer of constant thickness is proportional to the temperature difference across the layer

and the area normal to the direction of heat transfer, and is inversely proportional to the thickness of the layer. Therefore, the governing equation for the conduction of heat from inside of the cooling tank to outside part is Fourier's law of heat conduction.

$$Q = KA \frac{\Delta T}{\Delta x} \quad (6-1)$$

Where the constant of proportionality K is the thermal conductivity of the material, which is a measure of the ability of material to conduct heat from table 4:2. All used material thermal conductivity values are listed.

It indicates that the rate of heat conduction in a direction is proportional to the temperature gradient in that direction. Heat is conducted in the direction of decreasing temperature, and the temperature gradient becomes negative when temperature decreases with increasing thickness of the cooling tank material. Therefore, a negative sign is added in to make heat transfer in the positive x direction a positive quantity.

Temperature is a measure of the kinetic energies of the molecules. In a liquid or gas, the kinetic energy of the molecules is due to the random motion of the molecules as well as the vibrational and rotational motions. When two molecules possessing different kinetic energies collide, part of the kinetic energy of the more energetic (higher temperature) molecule is transferred to the less energetic (lower temperature) particle, in much the same way as when two elastic balls of the same mass at different velocities collide, part of the kinetic energy.

Convection is the mode of energy transfer between solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, surface of cooling tank is exposed to surrounding wind convection is called free (or natural) convection if the fluid motion is caused by buoyancy forces induced by density differences due to the variation of temperature in the fluid The rate of heat transfer by convection is determined from Newton's law of cooling.

$$Q_{cov} = hA(T_f - T_s) \quad (6-2)$$

Where h is the convection heat transfer coefficient, A is the surface area through which heat transfer takes in the outer side of the cooling tank place, T_s is the surface temperature, and T_f bulk fluid temperature away from the surface. (At the surface, the fluid temperature equals the surface temperature of the solid.).

The convection heat transfer coefficient h is experimentally determine parameter value depends all the variables that influence convection such as the surface geometry, the nature of fluid motion, the properties of the fluid, and the bulk fluid velocity.

Using total surface area of the cooling tank which have five side bounded and one side is open to the atmosphere is cooled by air which flow over the outside surface of the cooling tank. Minimum amount of the wind speed in the site of Bahir Dar is taken 2.5m/s according atmospheric science data based on site. [17] Wind speed and the collector outer temperature which can intern in the cooling tank. Temperature reach up to

51o.Heat transfer simulation is execute based on those parameters. Surface area of the cooling tank with fins to increase contact area of air and cooling tank. All simulation result is show in figure below with parametric dates of the result.

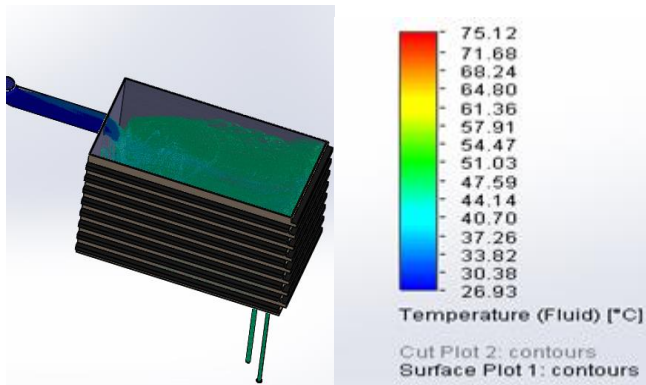


Figure 6:1. Heat exchanging simulation result in the cooling tank.

Temperature of water decrease gradual in the cooling tank due to heat loss in the side and bottom face of cooling tanks this is happened due to the present of air flow over the cooling tank. Density of air which pass over the cooling tank also decrease. Show in figure 6:1

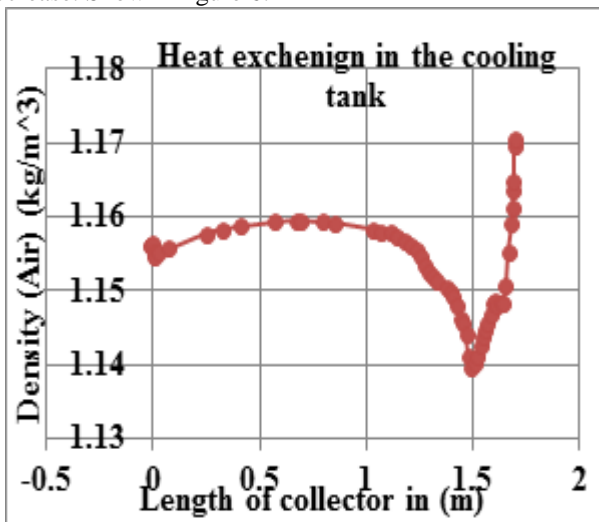


Figure 6:2. Density of air Heat flow

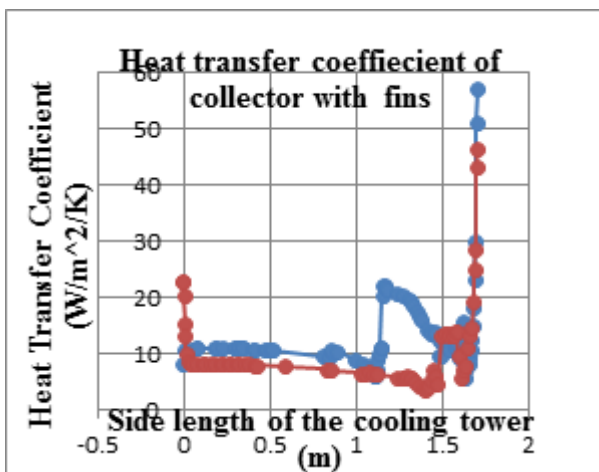


Figure 6:3 graph of air density variation in the flow direction

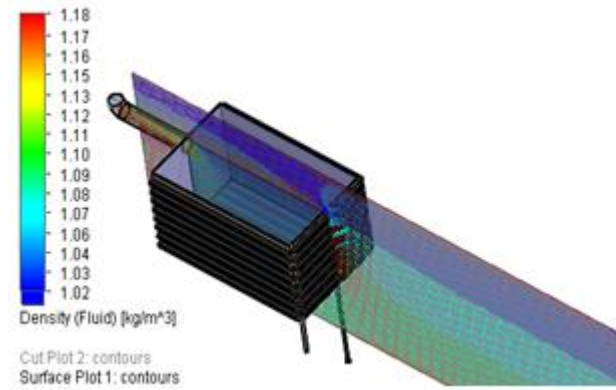


Figure 6:4 graph heat transfer coefficient in the cooling tank with and without fine

Due to variation of surface contact area heat transfer rate can vary so fins on the outside surface on the cooling tank increase the cooling process.

VII. TURBINE DESIGN

7.1. Pelton Wheel Turbine

Proposed model of Thermo syphon system solar energy electric generation model operates under dynamic pressure of water, with less quantity of water pure impulse turbine work under dynamic pressure of jet of water. Buckets are sort on edge of circular wheel (runner) mounted on horizontal shaft. Dynamic pressure of water have tendency to develop mechanical energy. Buckets deflect the jet through an angle of about 160 -165 in the same plane as the jet. After doing work on the buckets water discharged in the tailrace, and the whole energy transfer from nozzle outlet to tailrace takes place at constant pressure. So the jet is perpendicular to the buckets the total pressure energy should be zero at the time of collision of bucket and water jet, after collision, water flow in the draft tube pipe in the system, it discharge in the mixing nozzle in the system show in figure 6:1, Water enter into the casing of turbine normal to the center face of bucket and discharges backward, both inlet and outlet flow is tangential flow type the show in figure 6:4. Casing of a Pelton wheel does not perform any hydraulic function but it is necessary to safeguard the runner against accident and also to prevent the splashing water and lead the water to the tailrace in the system have the same function.

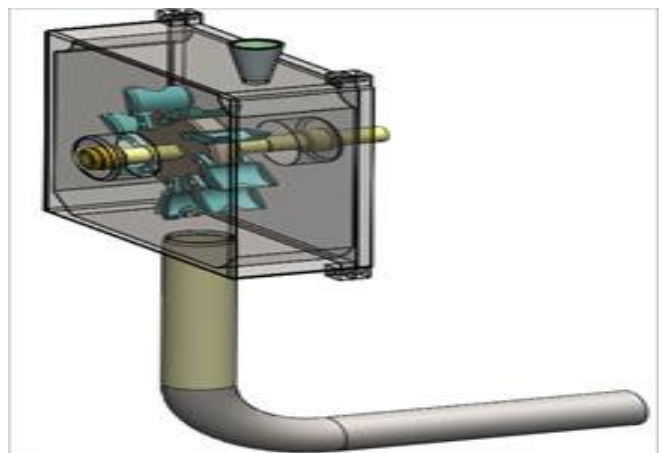


Figure 7:1 pelton wheel turbine assemble with delivery nozzle and draft tube

7.3. Mechanical Energy

The proposed model Thermo syphon system solar energy electric generation system operates under dynamic pressure of water, Potential energy of water in the cooling tank throw in the vertical downward passing through turbine delivery pipe which serves as a penstock and nozzle of turbine. Available Potential energy of the system change into kinetic energy which can make rotational mechanical energy in the turbine unit.

Velocity of free falling body is compute using equation 7-1

$$v = \sqrt{2gh} \dots \dots \dots \text{Equation (7-1)}$$

The required head is 1.35meter in the turbine delivery pipe show in figure 6:2 which including cooling tank height of 0.8m.

$$V = 5.15 \text{ m/s}$$

Available Power due to gravity at the end of the pipe is to be

$$\text{Force} = \rho ghx A_{cp2}$$

$$\text{Power} = \rho ghx A_{cp2} \times V$$

Where Acp2 is the cross section area of the delivery pipe, from standard pipe catalogue internal diameter of turbine delivery pipe is selected 30.1mm galvanized steel pipe d2.[16]

$$A_{cp2} = 7.112 \times 10^{-4} \text{ m}^2$$

$$\text{power} = \rho gh A_{cp2} \sqrt{2gh}$$

$$P = 48.28 \text{ watt}$$

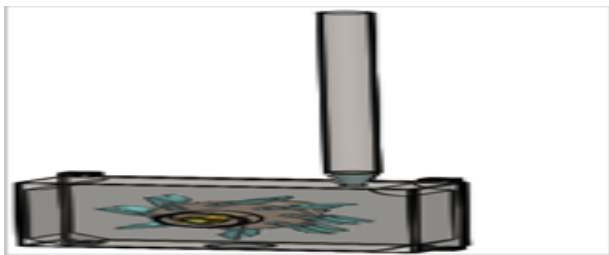


Figure 7:2 pelton wheel turbine assemble with delivery nozzle and delivery pipe

Flow Analysis in the Turbine

7.3.1 Velocity Triangles

The velocity diagrams of Pelton wheel turbine shown in Figure 6:4 Since the angle of entry of the jet is nearly zero, normal to the bucket surface area, inlet velocity triangle is straight line, as shown in figure 6:4 (a) below, if the bucket is brought to rest, relative fluid velocity V1, is the difference of jet velocity and bucket speed. The angle turn due to jet velocity in the horizontal plane during its passage over the bucket Surface is α maximum angle of bucket turn holding with water is 154.96oc show in figure 7:4 (b) and (c) vertical arrangement of nozzle make water fall in the draft pipe due to gravity after it turn with the bucket show in the figure 7:4 (b). Relative fluid inlet velocity can compute from velocity triangle.

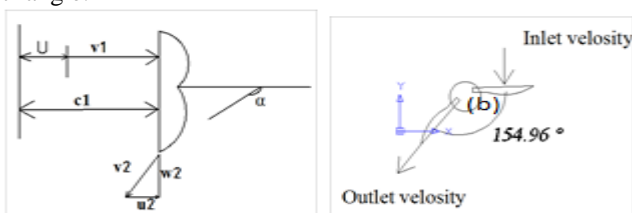


Figure 7:3 Velocity Triangles of pelton wheel turbine Orientation of blade in the model show in figure 6:4 (b) velocity triangles for a pelton wheel using Euler's turbine equation.

$$E = u(c_1 - u)(1 - \cos \alpha)/g \dots \dots \dots (7-1)$$

The unite of E being watt per second weight of flow, maximum energy of the turbine produce can be determine by the following equation

$$E_{\max} = C_1^2(1 - \cos \alpha)/4g \dots \dots \dots (7-2)$$

The unite of E being watt per second weight of flow value of C1 is the velocity in the inlet of the turbine depend on elevation or height of the turbine delivery pipe but in the system nozzle is used to increase the velocity of jet show in figure 6:1. potential head of 1.35m before nozzle of turbine, Jet velocity of the fluid before enter in the nozzle of turbine deliver velocity is based on the principle of free falling body to increase the velocity of jet in the system nozzle assemble on the bottom surface of turbine delivery pipe, after the nozzle outlet velocity increase up to 10.675 m/s by means of reducing the outlet cross section area of nozzle in the flow direction, which is assemble on casing of turbine unit show in figure 6:1 rotor outer velocity is determine based on maximum jet velocity from Euler's turbine equation.

$$u_1 = C_1/2$$

$$E_{\max} = 4.419 \text{ watt per second weight of flow}$$

watt per second weight of flow mean the weight of the water at the inlet of the turbine is determine using the volume flow rate and the total density of water which give the mass flow rate in the turbine bucket multiply with gravitational constant.

$$\text{power} = E_{\max} \times \dot{m} \times g$$

$$\dot{m} = 3.509 \frac{\text{kg}}{\text{s}}$$

The value of volume flow rate is taken from flow analysis of the system in chapter two

$$\text{maximum mechanical power} = 152.120 \text{ watt}$$

This is the maximum fluid power which is available in the system, practical surface friction is always present all maximum available power is not utilized effectively.

$$v_{ti} \neq v_{to}$$

$$E = u(c_1 - u)(1 - k \cos \alpha)/g$$

Rotational speed of pelton wheel hydraulic turbine N is expirree

$$N = \frac{(h \times \dot{V})^{1/2}}{j} \dots \dots \dots (7-3)$$

Where j is the number of jet, h delivery head and \dot{V} flow rate of water which inter in to the turbine unit in the proposed system fluid inter in to the turbine using one delivery pipe.

$$N = 1.953 \approx 2 \text{ revolution}$$

Where k is the ratio of outlet and inlet velocity v_{to} and v_{ti}

$$k = v_{to}/v_{ti}$$

outlet velocity of water from the turbine blade is very small when compare with the inlet velocity due to the direct collision of jet with turbine blade, head is equal with the length of the turbine show in figure below length Lt = 38.60 mm when it orient in the vertical direction during rotation flow assist by gravity force.

$$k = 0.172$$

$$E = 3.28 \text{ watt per second weight of flow}$$

$$\text{usefull mechanical power} = 112.908 \text{ watt}$$

Actual energy used in the system Hydraulic efficiency of turbine

$$\eta_t = \frac{\text{usefull mechanical power}}{\text{maximum mechanical power}}$$

$$\eta_t = \frac{112.908}{152.120} = 0.753$$

Head losses occur in the pipe lines conveying the water to the nozzle due to gravity flow, friction loss and minor loss are very small the static head of water change completely into dynamic pressure. The overall efficiency (η_o) for large Pelton turbine is about 85–90% but in the thermo syphon system solar energy electric generation. Turbine efficiency is low as compare with large pelton turbine efficiency.

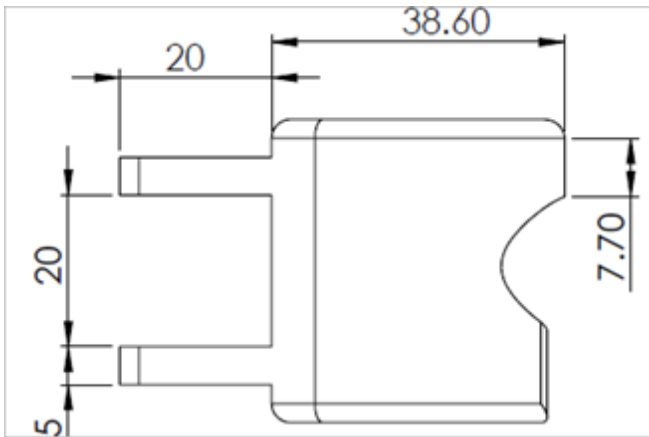


Figure 7.4 geometry of turbine blade

$$A_t = 1158 \times 10^{-6} \text{ m}^2$$

If $\alpha = 180$ the maximum hydraulic efficiency is 100% in practice the deflection angle is in the order 160-165° maximum dynamic pressure on the turbine surface due to gravitational energy 54,592.86 Pa when it fail on the turbine blade which have surface area of $1158 \times 10^{-6} \text{ m}^2$. To get maximum amount of pressure on the turbine blade Nozzle used to increase velocity of jet under subsonic flow condition, flow velocity caused by gravity is 5.15 m/s result of flow simulation which is used environmental pressure and gravity force dynamic pressure can increase by increasing jet velocity show figure 6:8 below.

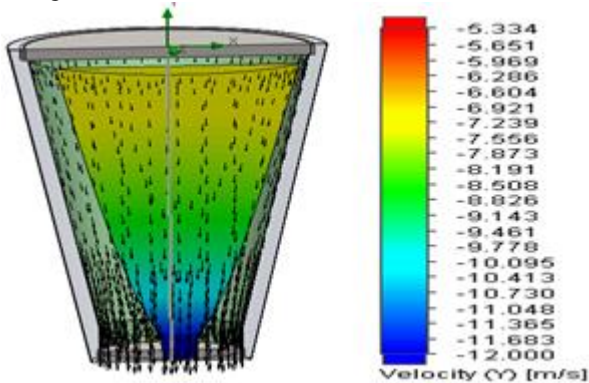


Figure 7.5 Turbine delivery nozzle flow simulation result

All dimension used in the flow simulation analysis, taken from two dimensional drawing and the initial condition of static pressure of water from head of 1.35 m taken in the inlet boundary condition, velocity increase in the down ward direction show in the figure 4:6 cut plot result data, negative sign indicate flow is in the down ward direction maximum velocity of water show in the range of 10.413 -10.73 m/s, due

to the flow velocity, dynamic pressure also increase which is the desired parameter in the pelton wheel turbine.

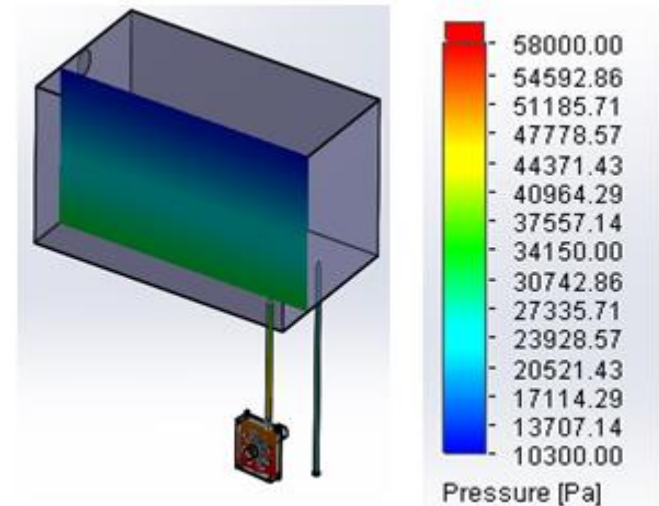


Figure 7.6: Free falling flow analysis from the cooling tank to turbine unit simulation result.

From the result of flow simulation dynamic pressure of water increase in the down ward direction because of free falling velocity increase from the top cooling tank to the end of nozzle outlet after the nozzle dynamic pressure record at the range of 51,185.71 up to 54,592.86 Pa show with mixture of yellow and red color in the flow simulation model due to outlet velocity of nozzle. Nozzle outlet velocity, is two times greater than inlet velocity. It show in the figure 6:7 on turbine delivery nozzle flow simulation analysis.

7.4. Shaft Work

Transmission of Energy using rotating shaft is common to produce electric power, force F acting through moment arm to generate torque the torque T applied to the shaft is constant, For a specified constant torque, [3] the work done during N revolutions is determined as follow

$$T = Fr$$

Where F is the product of pressure and surfaces area of the turbine

$$F = P_s \times A_t$$

At area of the turbine face and p_s static pressure of water from the height of 1.35 m

$$P_s = 13,044.85 \text{ Pa}$$

$$F = 15.11 \text{ N}$$

Force which is get from the static pressure is small on the same surface dynamic pressure can increase using nozzle on the top of turbine housing maximum dynamic pressure is reach up to 54,592.86 Pa after the nozzle is assemble show in figure 6:7 flow simulation result data.

$$F = A_t \times P_{\max}$$

$$F = 63.22 \text{ N}$$

This force acts through distance which is equal with the radius measure from the center of the shaft to center surface of turbine blade is 7.3 cm which is equal 0.073 m .

$$T = 4.615 \text{ Nm}$$

Parts of turbine unit in the system show in the figure 6:8 total distance cover in two revolutions are determine as follow.

$$S = 0.92 \text{ m}$$

Where N is the number of revolutions per unit time it compute from pelton wheel turbine parameter in section 6.2.1. With

two turbine revolution it is determine from pelton wheel turbine parameter. [3]Then the shaft work is determined from torque and moment arm which is 0.92m with two revolution of turbine blade.

$$W_{sh} = F \times S = \left(\frac{T}{r}\right) (2\pi r N) = 2\pi NT$$

$$W_{sh} = 58.162 \text{ Joule} = 2\pi NT$$

The power transmitted through the shaft is shaft work done per unit time. The turbine Shaft rotate two times in one second which is taken from the turbine parametric equation of pelton wheel turbine based on the system head and amount of discharge in the turbine unit. $\dot{W}_{sh} = 2\pi NT/t$

Within one second turbine can produce power.
 $\dot{W}_{sh} = 58.162 \text{ watt.}$

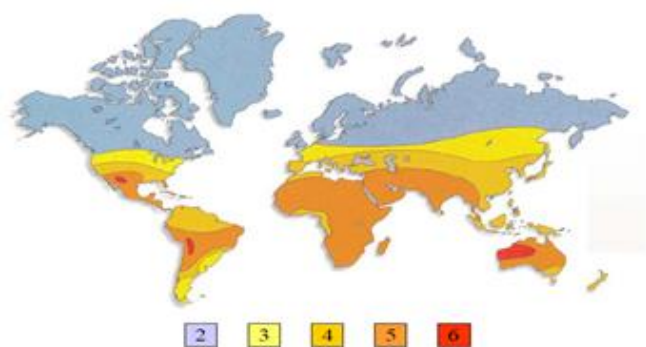


Figure 7:7 World isolation map yearly average of day light hour of sunlight

World isolation map, this map roughly divide the world in to five region based on yearly average of day light hour of sunlight. Average Sunshine hour in Bahir Dar is indicate on the bright yellow color which have 4hr. So that turbine unit can produce mechanical power in 5hr production period total production capacity is product of time and shaft power.

$$\text{Total shaft power in 4hr, } \dot{W}_{sh} = 837,532.8 \text{ Whr}$$

Hydraulic Efficiency of the turbine is 75.3%, all total shaft power is not convert in to useful power. Power production decrease due to turbine efficiency. So daily production capacity of the turbine is reduce into 630,662.1984wh or 630.7kwh shaft power can produce. Total thermo-syphon system solar energy electric generation system efficiency is the combination of collector efficiency and turbine efficiency mainly. It is 24.096%

VIII. CONCLUSION

The proposed thermo-syphon System can produce electric power. The variation of density case to static head develop on the side of collector and turbine with cooling tank and free delivery pipe, the elevation or height of collector side make variation of height to reach at equilibrium static pressure head of working fluid.

Before reaching equilibrium position, working fluid can change flow direction. Height of the solar collector outlet and cooling tank with variation of height 2.4cm due to volumetric expansion and density variation of water. Fluid which reach in the top pipe of the collector, flow in the cooling tank and hot fluid which came from the collector cool by natural cooling mechanism.

Nozzle increase jet velocity at the turbine inlet turbine housing from 1.35meter head fall on pelton wheel turbine, can use kinetic energy of fluid from this head can produce electric power coupled with generator with Hydraulic efficiency of 75.3%.

Water used as working fluid in the system, it have high density to produce high energy in the turbine unit relative to other fluid and it also free from chemical reaction formation with steel pipes, different fitting equipment's and mostly available with minimum cost.

Flat plat collector use to rise temperature of water 51oc, this variation of temperature in the system develop 2.4cm height variation between the solar collector and cooling tank proved flow in the cooling tank, Before reaching statics equilibrium position, working fluid can change flow direction in the cooling tank. So that proposed system can circulate water with effective manner. Daily production capacity of the system is 11.5872 kWh which is used to small appliance just like lightning, television and radio operation.

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